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Congestion management in power systems – A review

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ABSTRACT

In the past few decades, restructuring has overtaken all possible domains including the electric supply industry. Restructuring has brought about considerable changes by the virtue of which electricity is now a commodity and has converted into deregulated one. Such a competitive market has paved way for innumerable participants. This has led to overloading and congestion of transmission lines. Moreover, open access transmission network has ingenerated a more intensified problem of congestion. Thus, congestion management in power systems is germane and of central importance to the power industry. In this paper a review work is carried out to unite all the publications in congestion management.

Introduction

With the ever growing demand and recursively increasing advancements in technology, electricity market was also shifted from being regulated to deregulated market. In the earlier days, the electricity market was under a monopoly. One large utility had the authority of generation, distribution as well as transmission, usually known as vertically integrated utilities.

This called for the need of restructuring the industry. But there were a lot of challenges in a deregulated market which includes choosing an apt auction strategy for the electricity, mitigating market power of the participants, alleviating transmission congestion and related locational price spikes, maintaining system reliability, assessing market equilibrium and market efficiency [1].

Of these challenges the recently focused one is congestion management. In an open access environment, power flows from suppliers to consumers with transactions happening through transmission lines. Congestion takes place when the transmission lines are not sufficient to transfer the power according to market desires. Thus, congestion management is a tool for efficiently making use of the power available without violating the system constraints.

Congestion management refers to avoiding or relieving congestion. In a much broader sense, congestion management can be classified under two broad paradigms. One is the cost free method and other is the non-cost free method. The cost free measures include those which are at the disposal of the Transmission System Operator (TSO). These employs modifying the topology of the network, installment for transformer taps, operation of conventional compensation devices e.g. phase-shifters and use of Flexible AC Transmission System devices. These are coined as cost free measures because of nominal economical consideration. Hence, these measures would not involve the generation and the distribution companies. The non cost free measures include generation rescheduling and curtailment of load transactions.

Seema and Lakshmi [2] have embodied the conventional congestion management methods through a comprehensive review. But the topics covered are confined to general nodal pricing method, Price Control theme, congestion management through Genetic Algorithm, fuzzy logic, voltage stability, nodal and zonal congestions, a few points related to congestion management through FACTS devices and market based analogy.

The publications referred in this paper are from the following journals, proceedings and books.

IEEE TRANSACTIONS ON POWER SYSTEMS.
IEEE TRANSACTIONS ON ENERGY CONVERSION.
IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION.
International journal of electrical power system research (IJEPSR).
International journal of electrical power and energy systems (IJEPES).

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PROCEEDINGS OF VARIOUS IEEE CONFERENCES, REPORTS, REVIEWS & BOOKS.

The review paper is organized as follows: Section 'Conventional methods of congestion management' embraces upon the conventional methods of managing congestion. Optimization techniques are discussed in Section 'Optimization techniques and expert system'. The demand response management is included in Section 'Demand response management'. Section 'Congestion management in hybrid market' deals with the congestion management in hybrid markets. In order to get a glimpse of how helpful these techniques actually are, real time examples of various countries are discussed in Section 'Congestion management adapted in various countries'. Section 'Conclusions' gives the conclusion, review and recommendations for future work.

Conventional methods of congestion management

Nodal pricing method

The nodal prices vary according to the geographic locations, hereby giving them the name Locational Marginal Prices (LMP). The nodal prices lead to generation of heavy surplus. This surplus is then utilized to pay the 'contract rights'. A contract right gives the right holder the ability to inject power at one node and remove it at another in the transmission network [3].

LMPs are calculated in the following four ways. First, the system can be made to operate after 1 MW use and before 1 MW use. The difference in the two costs of operation then gives the LMP. This is barely practical. Second, LMP based on sensitivity factors of the marginal generators. The cost of generation at each generator can be calculated using this method. Third, LMP can be calculated as dual variables or Lagrange multipliers from optimal power flow (OPF). Fourth, LMP can also be obtained from 'transposed jacobian matrix' where the limiting constraints replace the rows and columns of the matrix [2].

In [4], the author has aimed to improve the outcome of social welfare problem by introducing some performance indices to compare different dispatch options thereby reducing total congestion cost along with. The method has been applied to three bus and eight bus test systems.

In [5], Sood et al. have proposed a generalized deregulated model applied to the IEEE-30 bus test system. This model dispatches the pool combined with privately negotiated bilateral and multilateral contracts and aims to maximize the social benefit.

In [6], Acharya and Mithulananthan, have analyzed and evaluated the effect of TCSC on spot price and congestion in deregulated electricity markets. The results thus obtained help in proving that TCSC can lead to reduction in congestion and losses.

Jokic et al. [3] has proposed a novel control scheme by using nodal prices in electrical power systems to achieve congestion management and optimal power balancing. They have also presented an explicit controller which detects all line flow constraints in steady state and guarantees economically steady-state operation.

Kang et al. implemented a novel zonal marginal pricing. The approach is based on congestion contribution identification and sequential network partition which was implemented on IEEE-39 nodes system [8].

In [9], Murali et al. used Bat algorithm based DC optimal power flow (DCOPF) to evaluate spot prices in single auction model while minimizing fuel cost and improving social welfare of the system. Bat algorithm is proved to perform better than Linear Programming (LP) and Genetic Algorithm (GA).

LMP reflects marginal cost comprising of both the generation marginal cost and transmission congestion cost. The costs are paid at respective nodes and the congestion charge is paid as a difference of LMP between the sink and source of a particular transaction, multiplied by the energy volume of each transaction. The advantage of this method is that it gives appropriate signals related to setting up of new transmission lines and installation of generators. But it also involves strategic gaming among the participants who wish to increase their profits.

Uplift cost

The former UK pool includes the congestion cost in the uniform price by addition of uplift cost.

Uplifts refer to the cost of security and equal to the difference between the total cost of supply in constrained and unconstrained cases [10].

The uplift cost includes transmission services uplift (the cost incurred due to the physical limitations of the network), energy uplift (the costs of demand forecast errors and generator shortfalls), reactive uplift (maintains system voltage within limits), unscheduled availability payments (the capacity payment paid to gensets that are available but are not required to run). The components are explained in detail in [3].

The uplift cost can be known mathematically as follows:

$$\text{PPP} = \text{SMP} + \text{Capacity Payment (CP)} \tag{1}$$

$$\text{PSP} = \text{PPP} + \text{Uplift} \tag{2}$$

where

SMP	it is the bid price of the marginal unit (the most expensive generator) required to meet forecast demand in a market period
PPP	pool purchase price, it is the price calculated before the day of trading
PSP	pool selling price, it is the price paid by buyers and paid to generators
CP	it is the payment for any available capacity, irrespective of whether the generators generated or not. It may rise during periods of shortages but falls when system capacity exceeds demand
Uplift	uplift payment covers the costs of transmission (including transmission system losses) and is the difference between the unconstrained schedule and the cost on the trading day
Bid	price predetermined variable costs

If in an unconstrained dispatch environment, a private generator is selected but not allowed to generate due to the system constraints, adjustment calculations are made to provide compensation for the generators.

$$\text{Adjustment}_{\text{constrained OFF}} = (\text{Capacity} - \text{Generation}) * (\text{PPP} - \text{Bid Price}) \tag{3}$$

Now, in case the original dispatch violates the security constraints, re-dispatch is needed.

Often, in the re-dispatch process, generators are paid the PPP which is lower than the bid price. This requires adjustment calculations as well.

$$\text{Adjustment}_{\text{constrained ON}} = (\text{Generation}) * (\text{Bid Price} - \text{PPP}) \tag{4}$$